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INFLATABLE STRUCTURE TEST PROGRAM

JOHN B. MONFORT

TECHNICAL REPORT AFFDL-TR-65-181

DECEMBER 1965

AIR FORCE FLIGHT DYNAMICS LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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FOREWORD

This report was prepared by the Structures Test Branch, Structures Division, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. The tests were performed under Project 1370 and directed by Mr. John B. Monfort, project engineer. Mr. Joseph R. Pokorski was responsible for all instrumentation and data reduction.

This report describes tests of Goodyear AIRMAT inflatable structures performed during the period from June 1964 to June 1965.

The material specimen tests were performed for Mr. J. R. Martuccelli of the Massachusetts Institute of Technology in conjunction with Contract AF33(616)-1155. The model tests were performed for Mr. S. J. Pollock of the Air Force Flight Dynamics Laboratory.

Results of model wind tunnel tests and the analyses of the data gathered in this test program will be found in reports written by the above individuals.

The manuscript of this report was released by the author September 1965 for publication as an RTD Technical Report.

This technical report has been reviewed and is approved.

Frederick C. Krug

FREDERICK C. KRUG
Colonel USAF
Chief, Structures Division

ABSTRACT

Small specimen tests (elevated temperature with internal pressure) were performed to predict the ability of a CS-105 silicone elastomer coated AIRMAT model to withstand the environment of a hypersonic wind tunnel (900-1500°F). The specimens all leaked badly in the expected wind tunnel temperature range. This indicated the probability of subsequent model failure. The wind tunnel model tests were successful however. Influence coefficient and vibration tests, both at room and elevated temperatures, were performed on AIRMAT models in support of flutter research. As before, the models could not withstand elevated temperature (800°F or above). The laboratory model inflation pressure was 10 psi compared with the wind tunnel model inflation pressure of about 2 psi. Time at temperature and/or an oxidizing atmosphere could be failure factors. Further testing of CS-105 coated AIRMAT structures is needed to evaluate the influence of load, pressure, temperature, and environment on coating characteristics and wire strength.

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SECTION I

INTRODUCTION

This report presents a description of elevated temperature, influence coefficient, and vibration tests performed on Goodyear Aerospace Corporation AIRMAT inflatable structures.

The program was initiated in June 1964 with thermal tests of small pressurized specimens in support of research being conducted by the Massachusetts Institute of Technology. The bulk of the program involved the determination of influence coefficients and the acquisition of vibration data from three delta configuration models. This testing, in support of flutter research, was performed for the Dynamics Branch of the Air Force Flight Dynamics Laboratory. The test program ended in June 1965.

SECTION II

TEST ARTICLES

The test articles were constructed of Goodyear AIRMAT. AIRMAT consists of two surfaces of thin woven wire cloth connected with "drop" wires. The cloth is coated with a silicone elastomer to allow internal pressurization when the edges are sealed in some manner. Type 304 annealed stainless steel wire was used.

Three delta shaped models were constructed and tested. The leading and trailing edges were formed by trimming back the drop wires to the tangent, shaping the surfaces into a semicircle, overlapping, and spot welding the joint. The closing rib (a steel plate) was used for mounting the model to a fixture and for pressurization access. The drop wires were trimmed a distance equal to the rib thickness and the cloth was placed in contact with the rib edge and spot welded. The joint was reinforced with a steel band screwed to the closing rib.

The first two models tested were coated with a silicone elastomer (S-2077) rated for a maximum temperature of 800°F. The third model was coated with an elastomer (CS-105) that would seal the structure at higher temperature.

Model dimensions were 53.4 in. x 24.9 in. span x 3 in. thick. All models were equipped with thermocouples, strain gages, deflection wire attachments, and load application hardware. In addition, the second and third models had integral accelerometer attachments.

Concentrated loads were applied and deflections measured on the first model only. Locations of load and deflection points are shown in Figure 1. The discrepancy between the load and deflection points location is due to the method used in building the models. Since only three models were required for test, it was not considered feasible to design and build a fixture that would insure accurate location of the points.

Accelerometers were used with the first and second models. The accelerometer locations for the first model are shown in Figure 1. Accelerometer locations for the second model are shown in Figure 2. There are only ten points shown in Figure 2 due to a consolidation of model test areas. No provision was made for accelerometer attachment to the first model. They were cemented instead to the load fittings.

A vibration rod attachment fitting was installed on all models. The vibratory load was applied to the leading edge at a point 2 1/4 inches forward of the trailing edge on the first model. Corresponding figures for the second and third models were 2 3/4 inches and 2 1/2 inches respectively.

Figure 3 shows the twelve load fittings which were spotwelded to the top surface wire cloth of the first model prior to coating application. Figure 4 shows the deflection fittings which were similarly installed on the lower surface. Figure 5 shows the 2 3/4 inches in diameter steel load plates used to distribute the compressive load into the model. The plates were counterbored to fit over the load fittings. The accelerometers are shown installed on the first model in Figure 6.

SECTION III

TEST SET-UPS

The AIRMAT specimen tests utilized a small cylindrical steel tank. One surface of the AIRMAT with drop wires cut off was installed over the open end. A bolted flange with gaskets was used to seal the specimen from leakage.

Following the one-surface specimen tests, the bottom of the tank was cut out, a flange was attached and the tank could be used for pressurizing actual specimens of AIRMAT.

The specimen test set-ups included radiant heat lamps mounted to water cooled aluminum reflectors, an air pressurization system, and for the one-surface specimens a means of measuring air leakage rates. The test set-up is shown in Figures 7 and 8.

The delta shaped models were mounted in a rigid holding fixture. The model closing rib was bolted at six inch intervals to the fixture. Radiant heat lamps mounted on water cooled aluminum reflectors were used to heat the upper and lower surfaces. Auxiliary lamps (not shown in the figures) were used to increase the leading and trailing edge temperatures to the test value (the upper and lower lamps provided most of the necessary heat).

Loads for influence coefficient determination were applied to the model with squares of lead plate. The lead was placed on a small steel platform welded to a 3/8 inch diameter steel rod. The rod was supported by guide plates and protruded through holes drilled in the heat lamp reflector to make contact with the load plates. The load rod was greased to help reduce friction.

Deflections were measured with potentiometers calibrated to an accuracy of ±1/4 percent of full scale. To reduce "pull" on the model, the potentiometers were modified by removing the internal spring and replacing it with a lead weight-pulley arrangement. Figure 5 shows the test set-up.

Strain gage output and deflections were recorded by the High Speed Data Acquisition and Processing System (HSDAPS). This system collects, records, analyzes, reduces, displays, and stores the transducer output.

The vibration tests utilized a five pound electro-magnetic shaker connected to the model attachment fitting by means of a 1/4 inch diameter steel rod. Natural frequencies were found through the use of accelerometers, an oscilloscope, and an electronic counter. The shaker excitation was provided by a sine wave function generator.

The accelerometers were Endevco Model 2226 and Model 2245B used respectively with the first and second models. The latter accelerometer is rated to a maximum temperature of 750°F.

Natural frequencies for the third model were determined from an accelerometer bonded to the lower end of the shaker (concentric on shaft). Nodal lines were found only at room temperature by means of sand, coffee grounds, or bird seed. The vibration test set-up is shown in Figures 9 and 10.

In addition to influence coefficient and vibration tests, the first and second model deflections under uniform load were measured. The loads were applied with paper and cloth bags containing lead shot. Deflections were processed through the data system. The test set-up is shown in Figure 11. The air pressurization system is shown in Figure 12.

SECTION IV

TEST PROCEDURE AND RESULTS - AIRMAT SPECIMENS

The AIRMAT specimen tests were performed as part of an attempt to predict model behavior in a hypersonic wind tunnel. Since the drop wires were not present with the one-surface specimens, the tests were performed at low pressure (2 psi). All specimens tested were coated with CS-105 silicone elastomer.

The first specimen was tested to determine crazing temperature, that is, the temperature at which the silicone coating would crack upon cooling. The specimen was heated to and cooled from various temperatures up to 1100°F at a rise rate of 1°/second. No cracking was evident although the material became very stiff and could be "oil canned". Leakage at 1100°F was approximately 0.1 CFM through 19.6 sq. inches of material.

Another specimen was heated to 850°F at a rise rate of 1°/second in an attempt to determine at what temperature a change in the coating characteristics occurred. This specimen appeared to be more brittle upon cooling than the previous one. Leakage was almost nonexistent at 850°F.

Thermocouple installations were also investigated. Eight specimens were fitted with thermocouples installed within the coating or in contact with the wire cloth. Surface thermocouples were bonded to these specimens with Sauereisen cement.

The third specimen was heated at a rise rate of 50°/second using a "buried" thermocouple to control the temperature. The coating burst into flames at a surface thermocouple temperature of 1200°F. Heating was continued to 1500°F (control). The surface thermocouple indicated a temperature of 1715°F.

The fourth specimen was heated to 1500°F at a rise rate of 1°/second. The coating did not burn although it emitted smoke at 700°F. The difference between surface and buried thermocouple outputs was approximately 35°F. Leakage became excessive at 1430°F.

The fifth specimen was heated to 1500°F at a rise rate of 5°/second. The coating emitted smoke from 900° to 1000°F, but did not burst into flames. The wire cloth burst at about 1460°F at a point adjacent to a welded thermocouple. The temperature difference between thermocouple installations was small.

The sixth specimen was heated at a rise rate of 10°/second. The coating burst into flames at about 1125°F. Leakage began at about 825°F. Heating was continued to 1500°F.

The seventh specimen was heated to 1500°F at an approximate rise rate of 200°/second. The coating burst into flames at around 750°F.

The eighth specimen was heated to 1500°F at a rise rate of 5°/second and the specimen coating ignited at about 1200°F. The flames died out at about 1300°F. Pressure was lost at about 1350°F.

Six of the specimens had strain gage installations. Of these, four were either open, intermittent, or shorted to ground prior to test. One of the others shorted to ground at 1200°F. The remaining strain gage was found to have an open circuit after the specimen cooled from 1500°F. The former operative gage was found to have poor sensitivity. The latter was not tested for sensitivity.

Three different strain gage installations were used. The gages were either cemented directly to the wire cloth, placed between layers of coating, or had the junctions welded to thin stainless steel tabs and placed between layers of coating. The two partially successful gages reflected the first and third methods of installation. The strain gages used were Model S-430 manufactured by the Budd Co.

Three specimens of AIRMAT (two surfaces) were tested in the modified air tank. The objective of the test was to achieve a temperature of 1500°F at an internal pressure of 10 psi. The rise rate was 1°/second.

The first specimen developed leakage at around 820°F followed by a pressure drop to 6 psi. This pressure was maintained for about 2 minutes and then increased to 10 psig. At about 950°F the pressure dropped to 8 psi and was returned to 10 psi. At 1000°F leakage became excessive.

The second specimen was tested in the same manner but at a pressure of 6 psig. Excessive leakage appeared at about 825°F.

The third specimen was tested at 5 psi. First leakage appeared at about 820°F. Excessive leakage occurred at about 1185°F.

Figure 13 shows the lower surface of the first specimen after cooling. It is to be noted that the coating has cracked, blistered, and flaked off. Also, the coating is hanging in beads around the flange. Possibly, this latter effect was caused from compression of the coating between the flanges due to unequal thermal expansion of the flanges and bolts. This effect, in itself, could have caused leakage, but around the flange, and not through the material. The coating cracks during cooling and there is no way to determine whether there was leakage through the specimen at the test temperature. There were no drop wire failures during the three tests.

One surface of an S-2077 coated AIRMAT specimen was heated to 650°F four times to observe any possible coating deterioration. Each time the temperature was maintained for only about ten minutes before cooling. There was no leakage or any apparent change in the coating.

The specimen was next heated to 700°F and the temperature was maintained for seven hours without air pressure. Periodically, the specimen was pressurized to 2 psi. After about 4 1/2 hours, excessive leakage developed. Upon cooling to room temperature, the specimen coating appeared to be thinner and was very porous.

On the basis of this test, it was decided to reduce the test temperature of the first and second models to 650°F and to attempt to collect all data during one heating cycle.

SECTION V

TEST PROCEDURE AND RESULTS - AIRMAT MODELS

The first delta wing model was tested for influence coefficients at both room temperature and 650°F. The test pressures at room temperature were 2, 4, 6, 8, and 10 psi. An attempt was made to apply load increments yielding a change in deflection of a magnitude at least equal to twenty times the accuracy of the deflection potentiometer. This was not possible either due to excessive model deflection at the tip or excessive dimpling under the load plate. In addition, loads applied at certain points had little or no effect on deflections at other distant points.

The loads were applied in four increments. After application of an increment, deflection measurements were made at all points. After peak load application, the loads were removed incrementally and deflections were measured. However, much hysterisis was present and this unloading phase was eliminated for the elevated temperature test.

At elevated temperature, the model was tested only at 2, 6, and 10 psi.

Natural frequencies were determined for at least six modes of vibration at each test pressure. The test pressures were 2, 4, 6, 8, and 10 psi for the first and second models at room temperature. The second model was further tested at 500°F and 650°F and at 2, 6, and 10 psi internal pressure.

The S-2077 coating applied to the first and second models showed no apparent deterioration from exposure to elevated temperature. Each model was heated only once to the test temperature. The first model had been heated three times to the coating curing temperature (500°F) for evaluation of the temperature distribution. The longest time at test temperature (about 6 hours) was experienced by the first model.

The third model was vibration tested at 2, 6, and 10 psi at room temperature, 300°F, 500°F, and 650°F. It was the intention to collect vibration data at 800°F and 1000°F also but the model burst at about 800°F before data could be taken.

The failed model is shown in Figures 14 and 15. The temperature distribution shortly before failure is shown in Figure 16. The upper and lower surfaces had been heated to approximately 800°F at a rise rate of 1°/second. After this, the model trailing edge was heated to test temperature. At failure, auxiliary heat to increase the leading edge to test temperature had not been applied.

At the time of failure, temperature data was being sampled at ten second intervals since imminent failure was not expected.

Smoking of the model upper surface near the aft end was noted shortly before failure. Upon bursting, the model coating ignited in the upper failed area. This was probably due to the failed material contacting the heat lamps. The model was vibrating at low frequency (about 18 cps) and amplitude at failure. The model inflation pressure at failure was 10 psig. The rupture is attributed to drop wire failure. The wires failed at the upper surface in an aft inboard area. There was no apparent leakage prior to failure.

Based on analysis by Goodyear (GER-11740), the drop wires had a factor of safety in tension of about three at the temperature and pressure of failure. The drop wire strength value was derived from tensile tests of cloth strips at room temperature and 780°F. Other points to plot a curve were based on strength data for Type 304 stainless steel. The individual drop wire strength was assumed to be the same as the warp wire strength since the drop wires are also woven in, being extra warp filaments. However, the drop wires are more critical because of their smaller number per unit area.

Strain gages were unreliable for the delta wing installations as well as the earlier test specimens. Monofilament gages were used. The gage consisted of .0007-inch Nichrome V wire, 1.1 inches long, spot welded at each end to a 1/4 inch square by .006 inch thick stainless steel tab. The assembly was installed face down within the coating.

Of the twelve gages installed on the third model, six had failed before the elevated temperature test. No additional strain gages had failed at model failure.

SECTION VI

CONCLUSIONS AND RECOMMENDATIONS

The CS-105 coated AIRMAT is subject to burst failure when a pressurized article is heated in an ambient laboratory atmosphere to a temperature of 800°F at an internal pressure of 10 psi.

Time at temperature and/or an oxidizing atmosphere could be failure factors.

Further testing of CS-105 coated AIRMAT structures is needed to evaluate the influence of load, pressure, temperature, coating curing time, and environment on coating characteristics and wire strength.

Since the weight of instrumentation is large in comparison with the test load and because deflections are small, special methods are needed to insure accurate load input and deflection measurements for an AIRMAT structure influence coefficient test.

POINT No	LOAD P'T UPPER SURF.		DEF. P'T LOWER SURF.		ACCELER. UPPER SURF.	
	X	Y	X	Y	X	Y
28	3.91	3.59	3.75	3.47	3.91	3.56
29	4.00	11.53	3.94	11.47	4.09	11.53
30	4.21	19.50	3.91	19.47	4.34	19.53
31	12.00	2.91	11.84	2.97	12.00	2.97
32	12.12	8.94	11.91	8.97	12.09	9.03
33	12.25	15.97	12.00	15.97	12.28	16.03
34	21.66	2.53	21.59	2.47	21.66	2.56
35	21.81	7.47	21.66	7.47	21.81	7.53
36	21.88	11.56	21.72	11.59	21.94	11.56
37	29.88	7.43	29.78	7.56	29.94	7.56
38	32.91	2.93	33.00	3.06	33.00	3.06
39	41.00	1.91	40.97	2.00	41.09	2.00

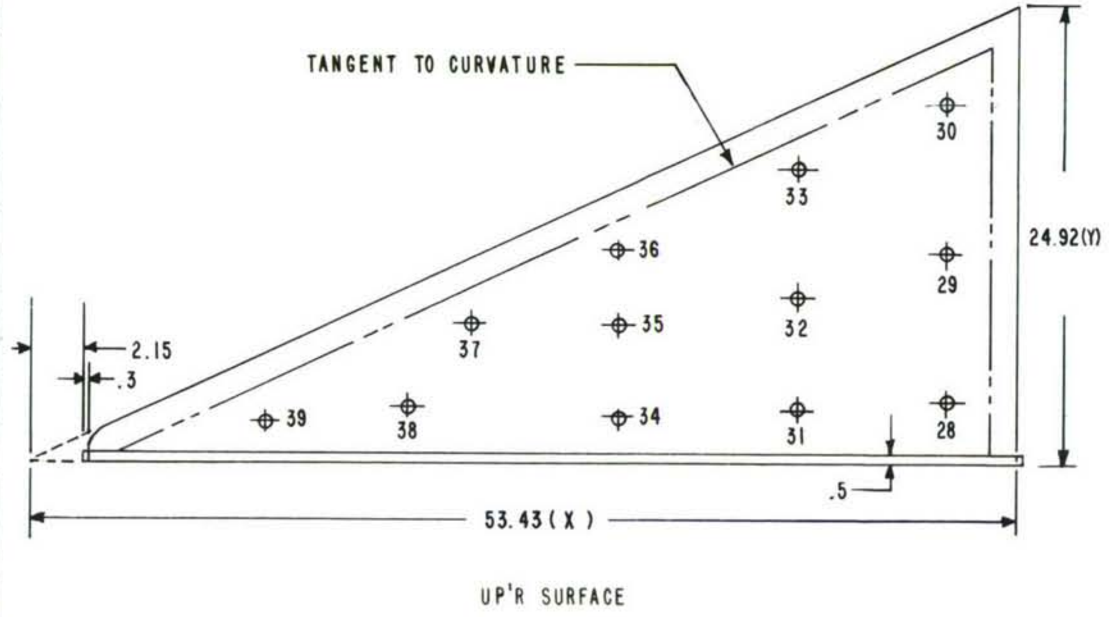

Figure 1. First Model - Load Application, Deflection, and Accelerometer Locations

POINT No	ACCELER-OMETER	
	X	Y
28	3.92	3.56
29	3.96	11.53
30	4.09	19.63
31	11.97	3.03
32	12.00	9.06
33	12.15	16.03
34	21.72	2.55
35	21.72	7.56
36A	21.77	12.58
38A	34.68	4.00

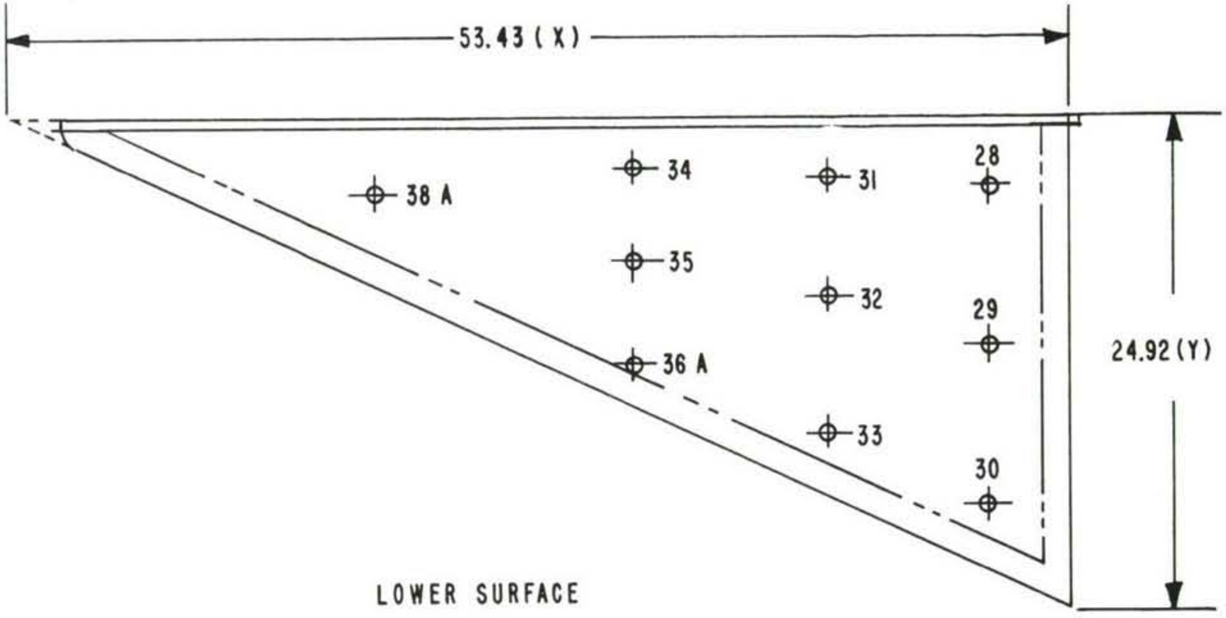

Figure 2. Second Model - Accelerometer Locations

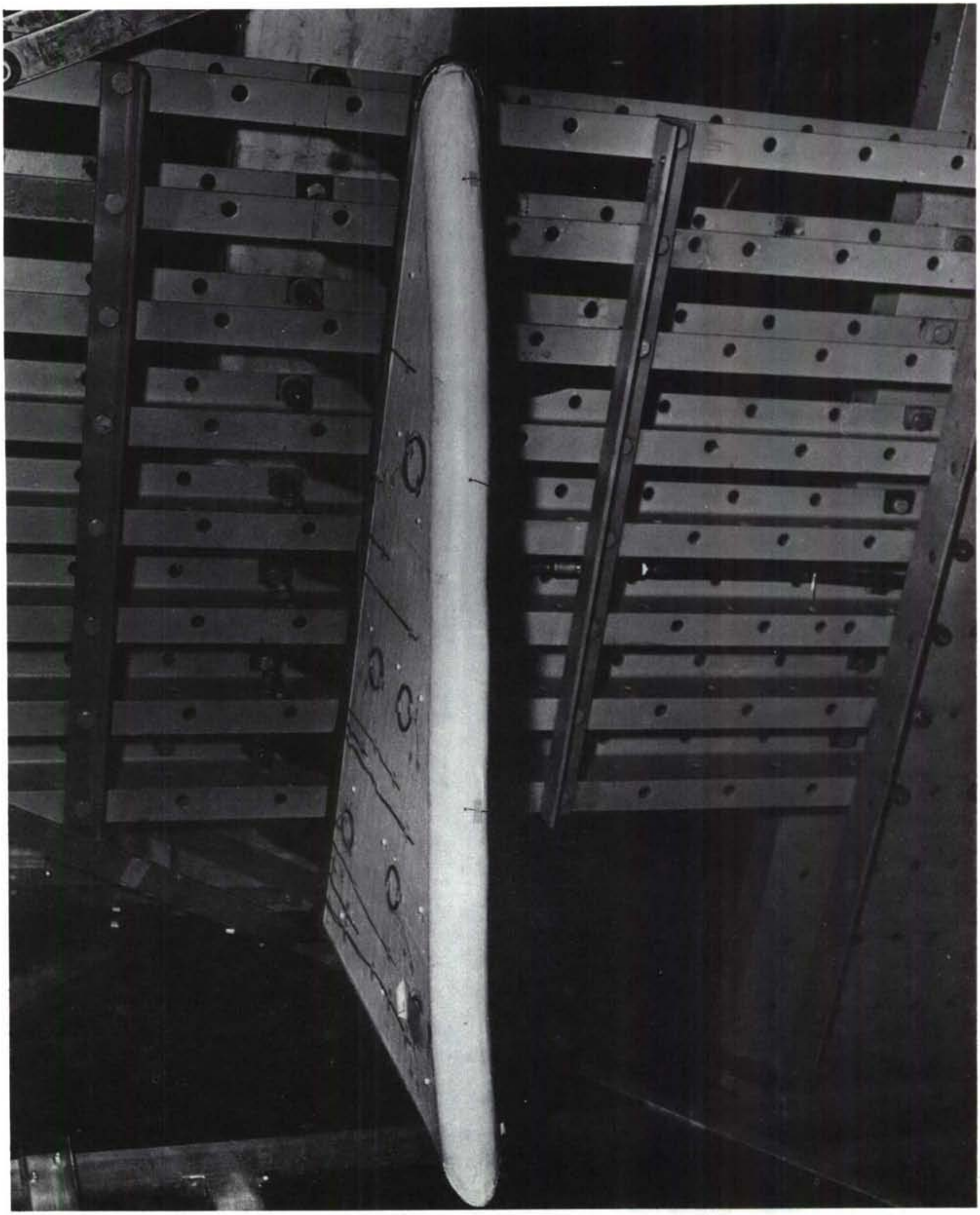

Figure 3. First Model - Top Surface

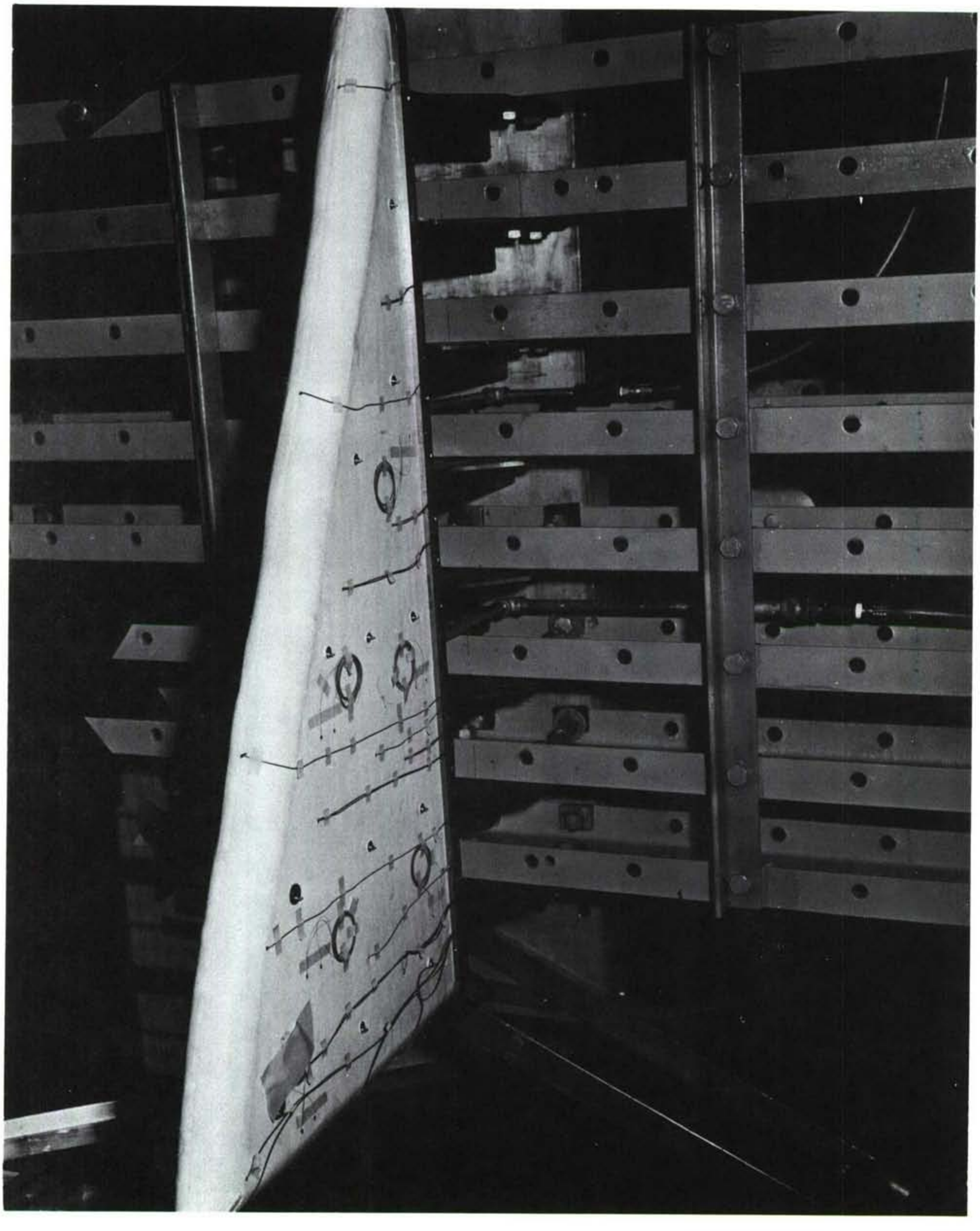

Figure 4. First Model - Bottom Surface

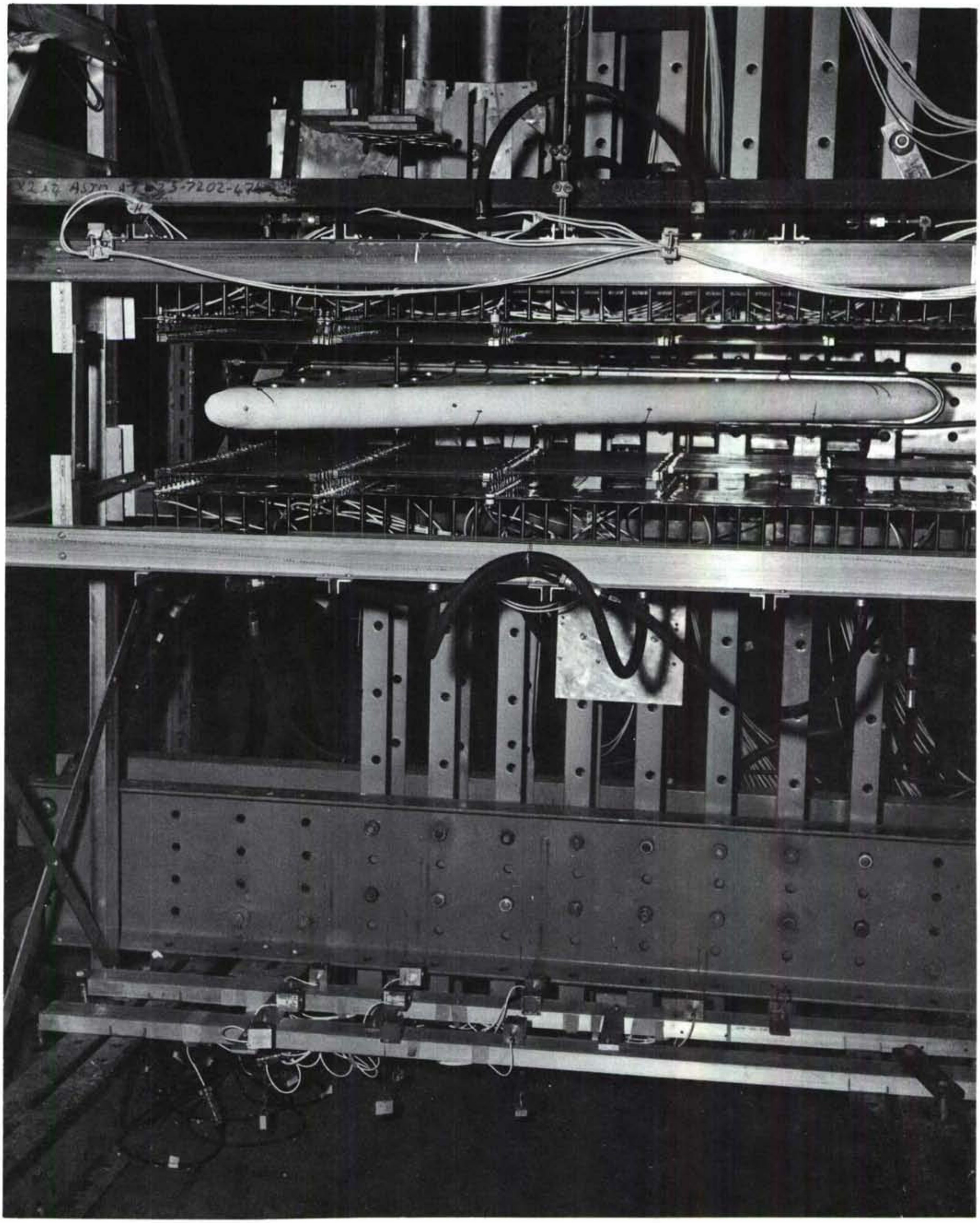

Figure 5. Test Set-up for Influence Coefficients

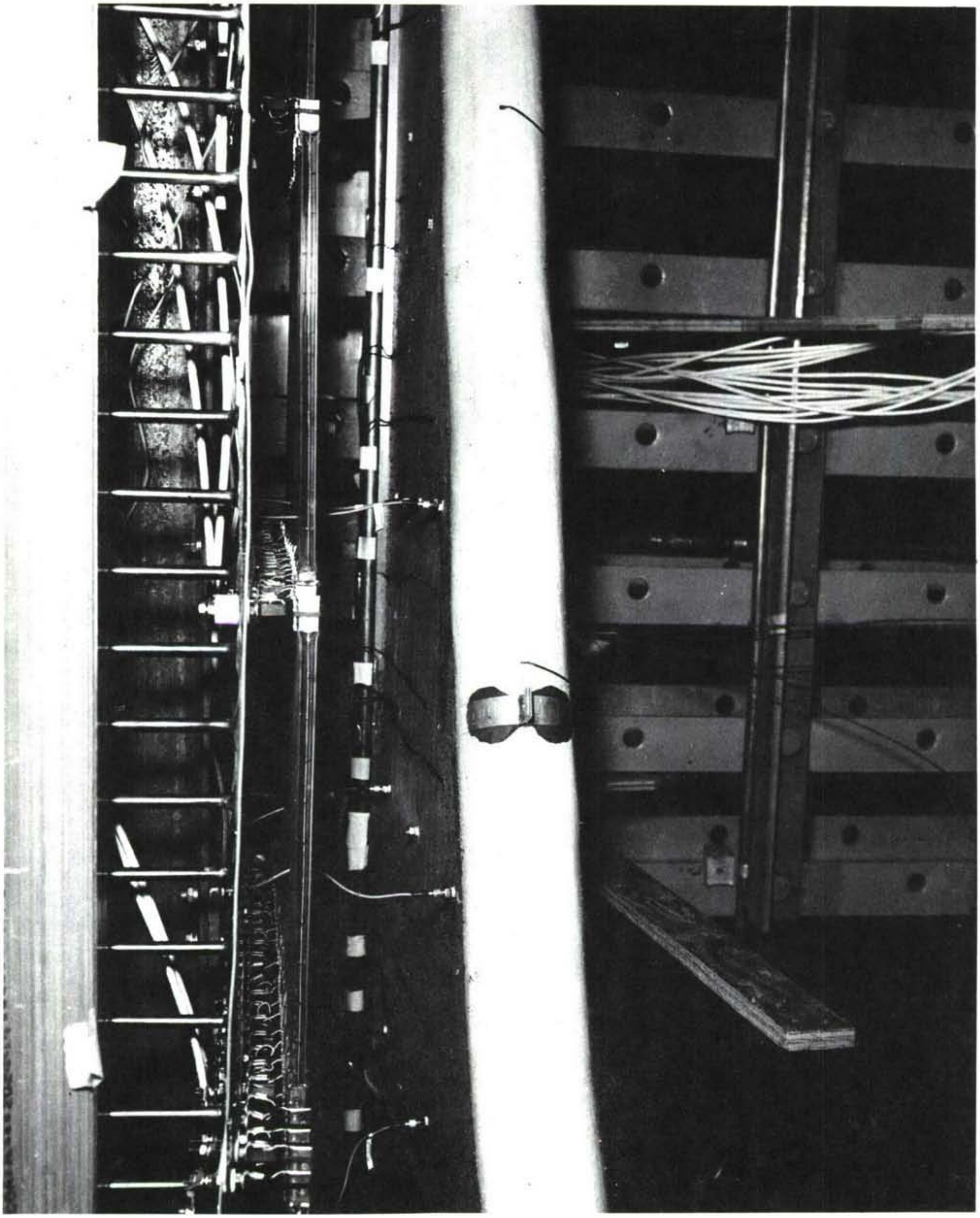

Figure 6. First Model - Accelerometer Installation

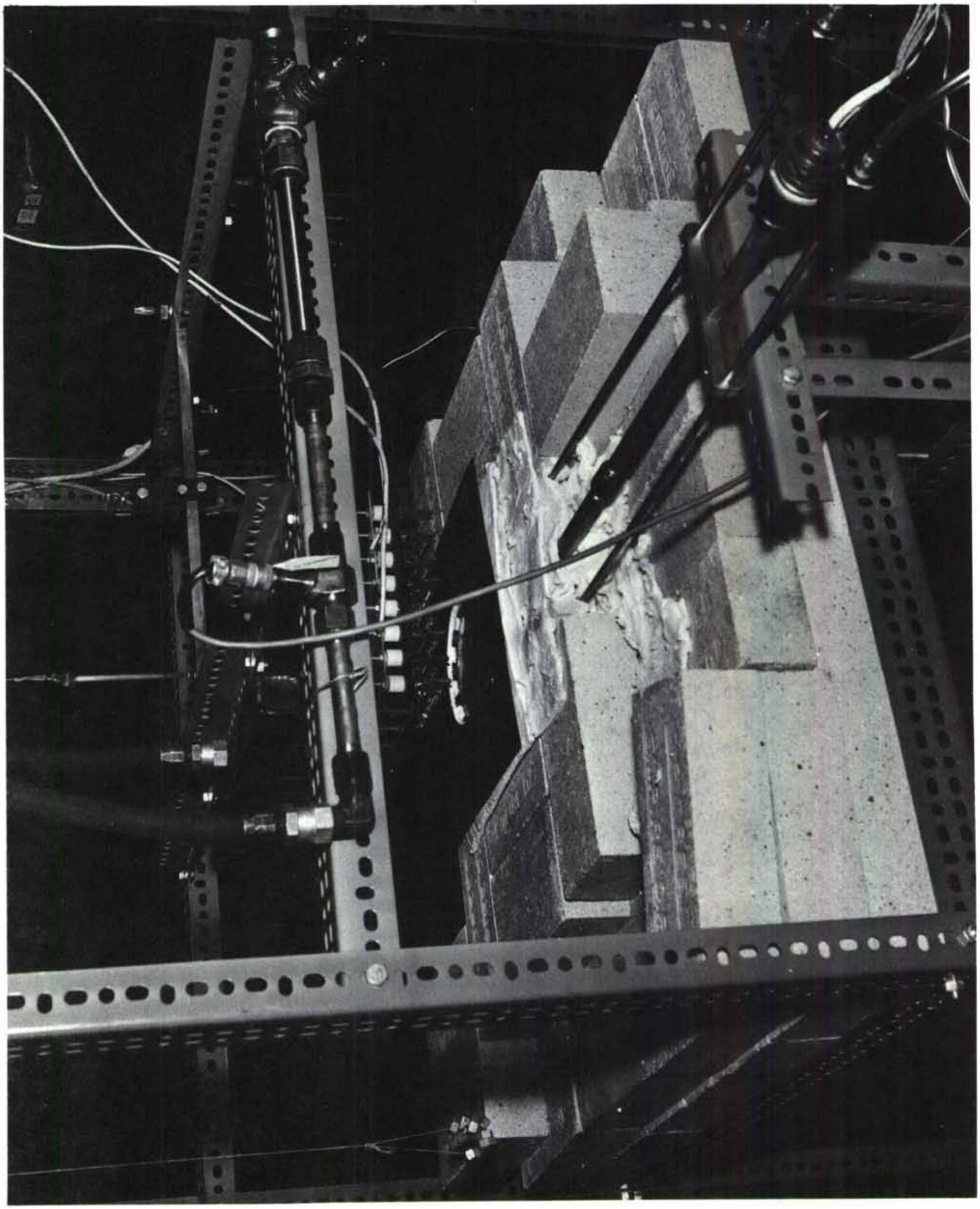

Figure 7. One-Surface Specimen Installation

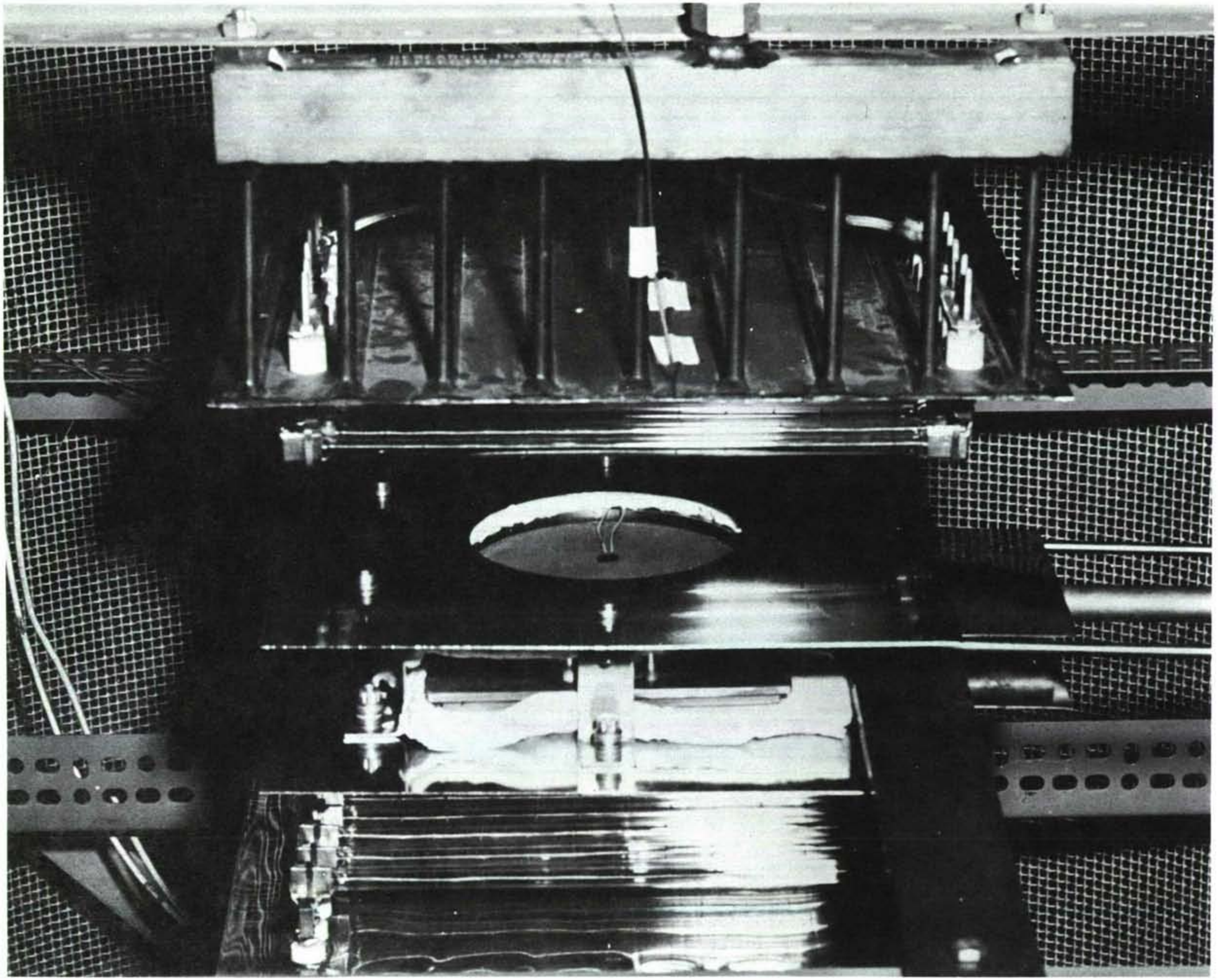

Figure 8. AIRMAT Specimen Installation

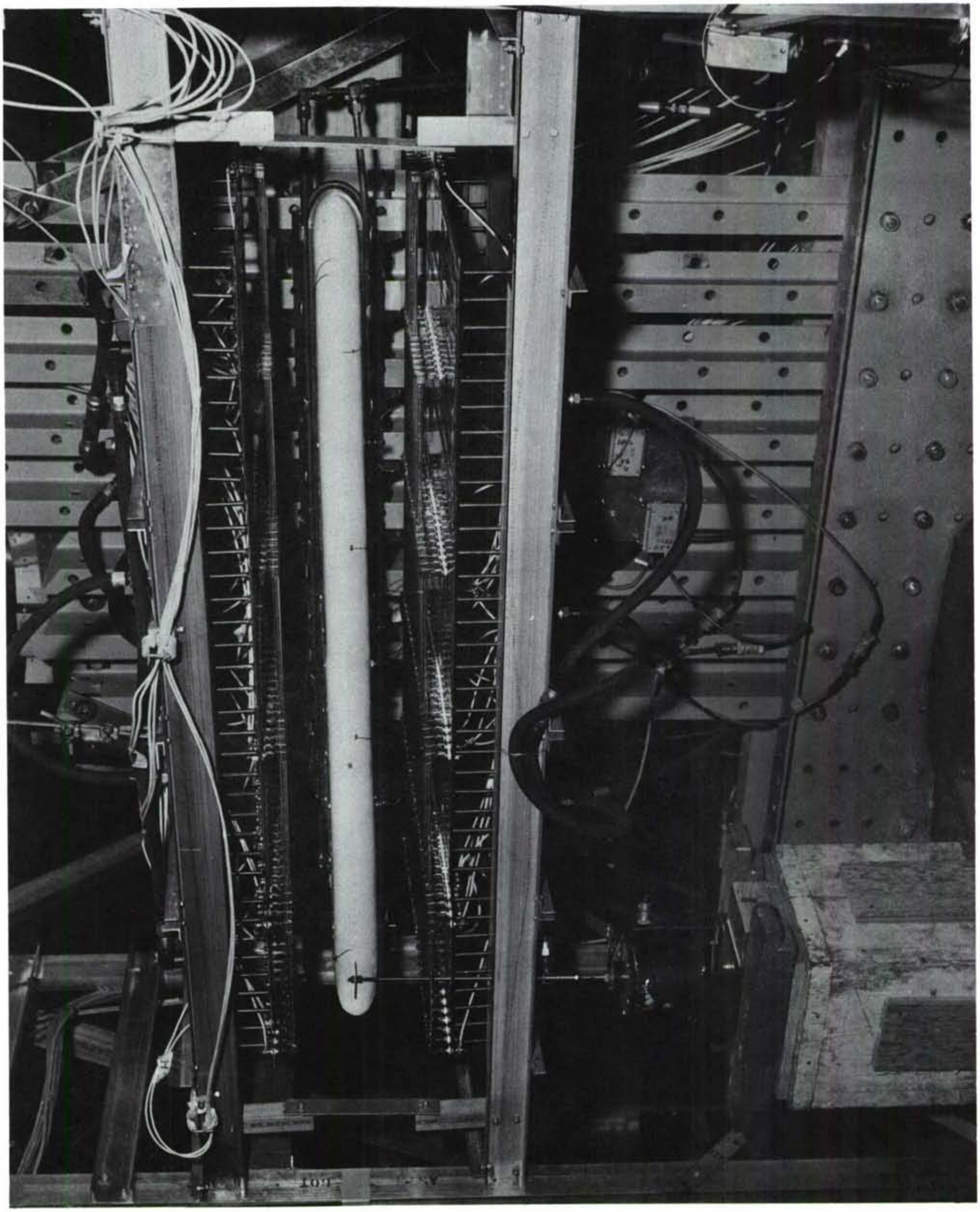

Figure 9. Second Model - Vibration Test Set-up

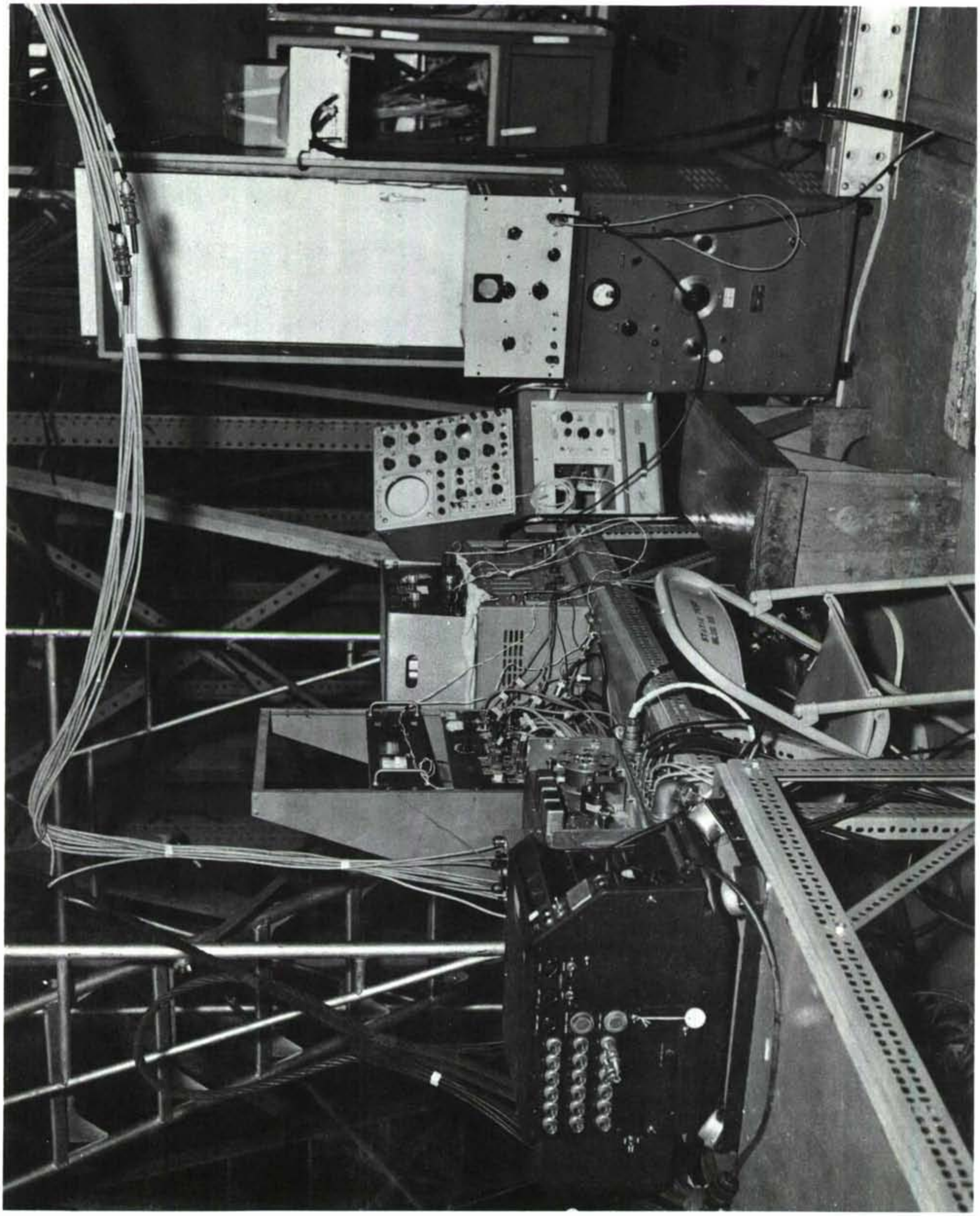

Figure 10. Typical Vibration Test Equipment

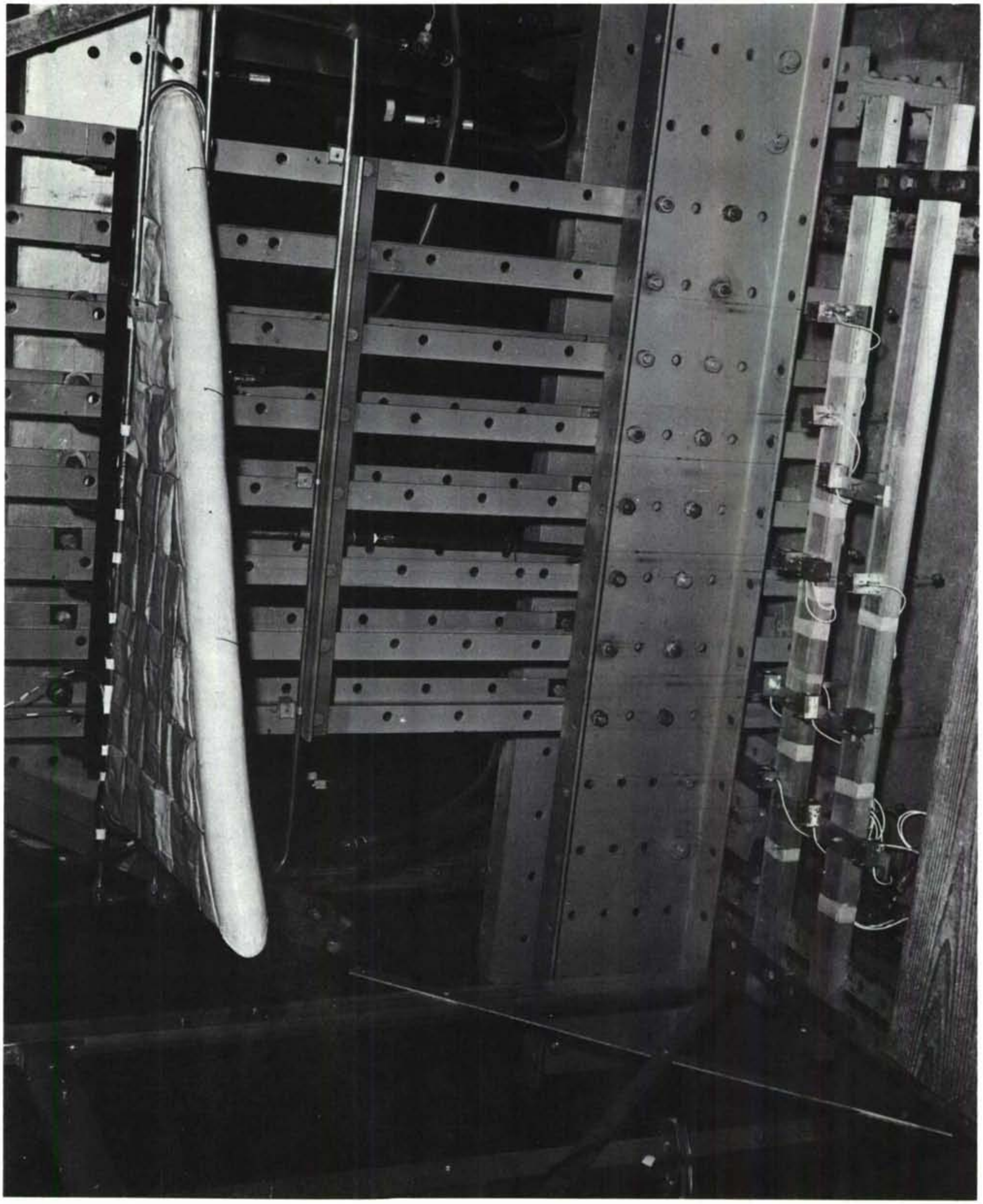

Figure 11. Typical Uniform Load Test Set-up

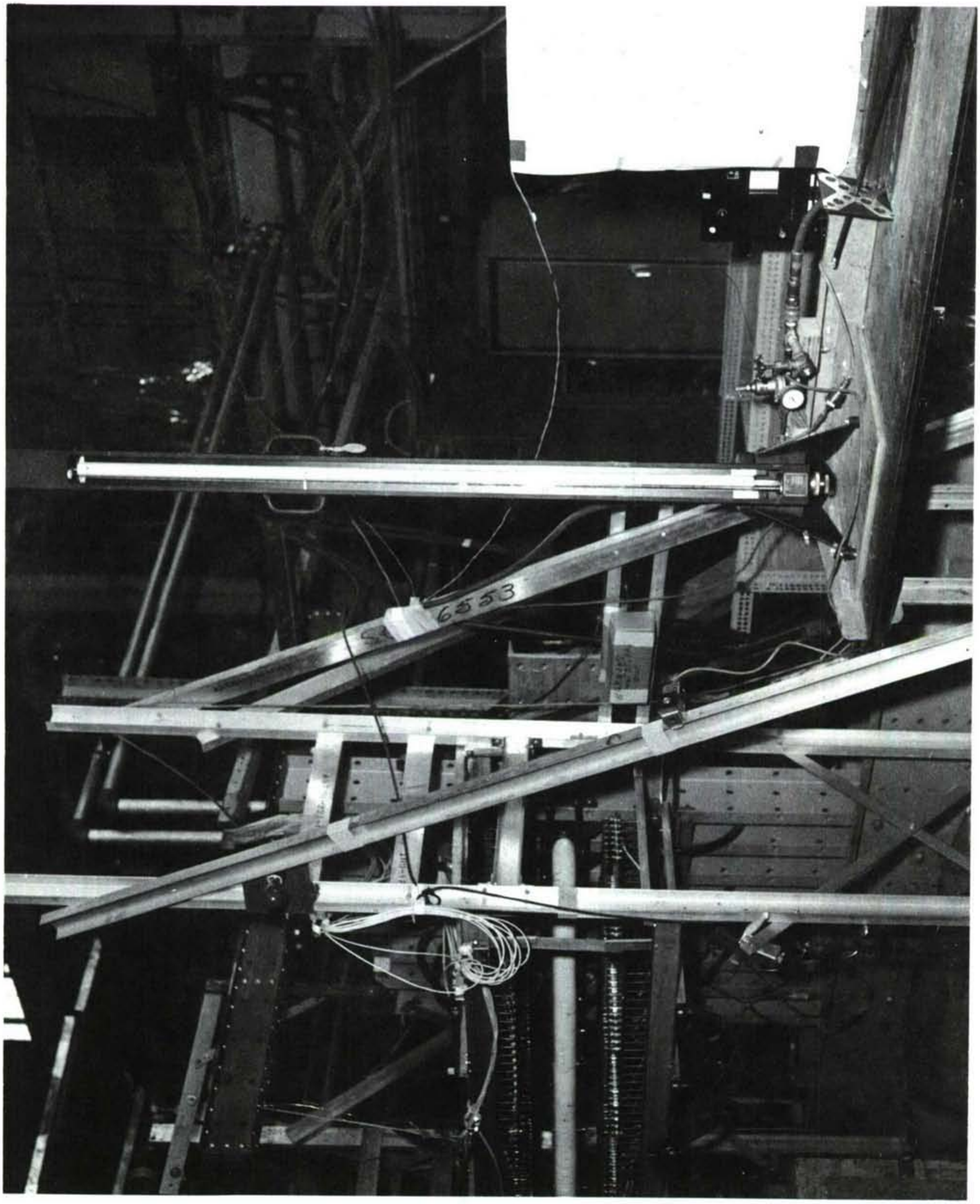

Figure 12. Air Pressurization System

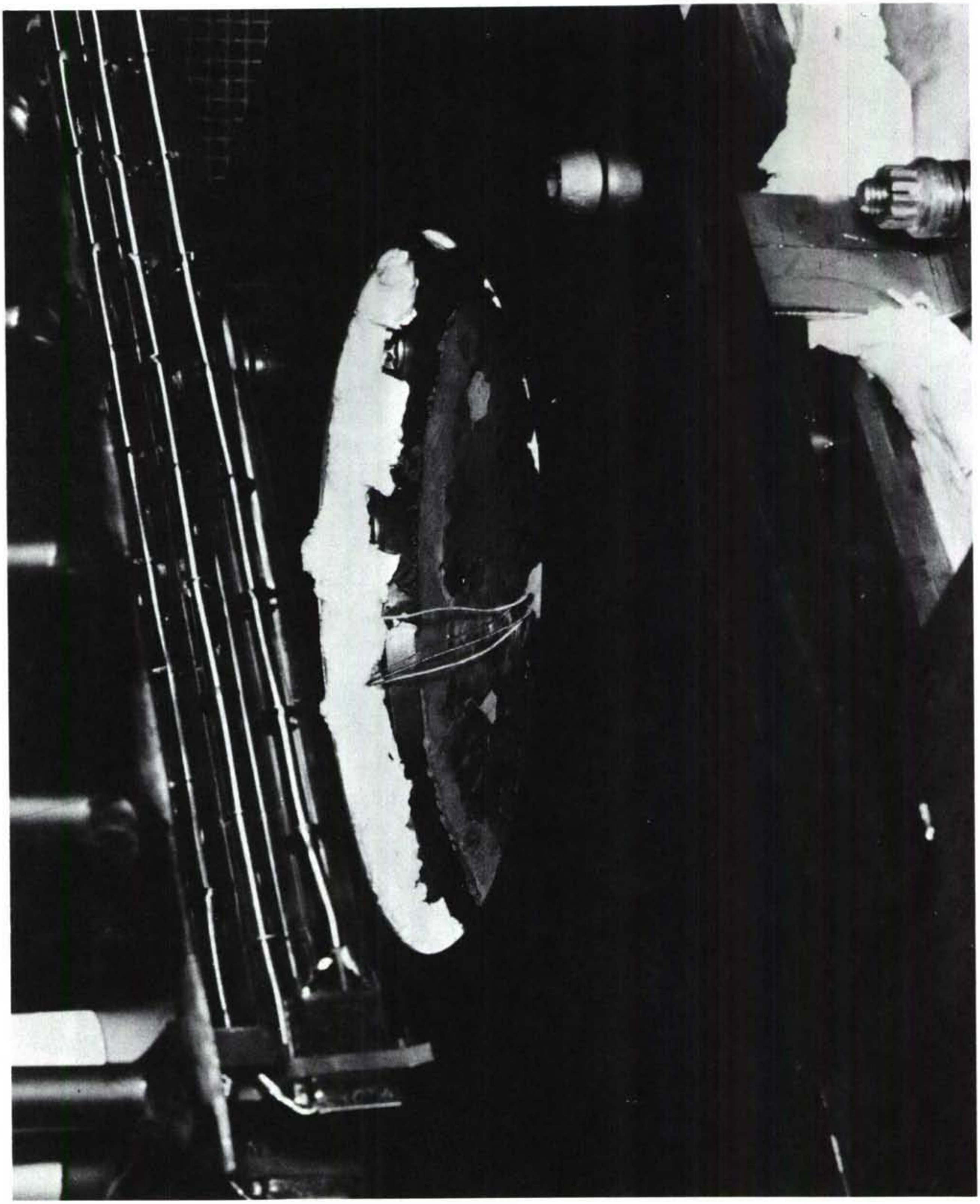

Figure 13. AIRMAT Specimen After Cooling

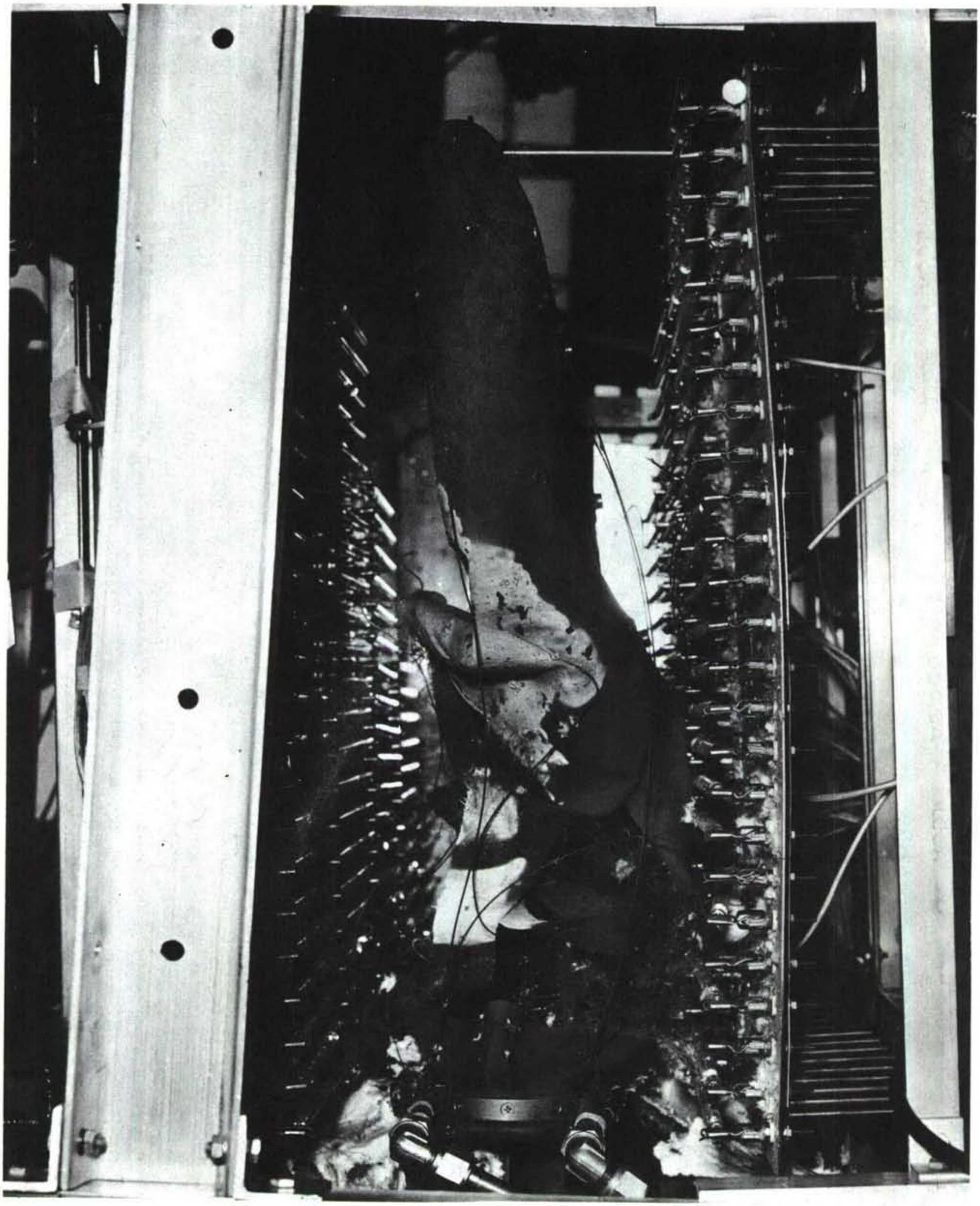

Figure 14. Third Model After Failure

Figure 15. Third Model After Failure

No	X	Y	REMARKS
1	4.50	6.50	TOP
2	14.80	4.50	↕
3	26.20	4.00	
4	36.50	4.00	
5	4.00	16.50	
6	14.30	13.50	
7	24.00	9.70	TOP
8	0.0	1.50	TRAILING EDGE
9	8.50	1.50	TOP
10	29.70	1.50	
11	46.0	—	LEADING EDGE
12	0.0	12.50	TRAILING EDGE
13	0.0	24.92	EDGE INTERSECTION
14	18.3	—	LEADING EDGE
15	32.90	—	LEADING EDGE
16	6.50	13.00	TOP
17	15.80	10.50	TOP
18	6.50	10.00	BOTTOM
19	15.8	7.50	BOTTOM
20	1.50	—	INTERS. OF TAN. (BOTTOM)
21	10.10	—	BOTTOM TAN.
22	0.0	8.5	TRAILING EDGE
23	3.50	—	LEADING EDGE
24	25.80	—	LEADING EDGE
25	44.50	—	TOP (ON TAN.)
26	44.50	—	BOTTOM (ON TAN.)
27	4.50	6.50	BOTTOM
28	14.80	4.80	↕
29	26.20	4.00	
30	36.54	4.00	
31	4.00	16.50	
32	14.30	13.50	
33	24.00	9.70	BOTTOM

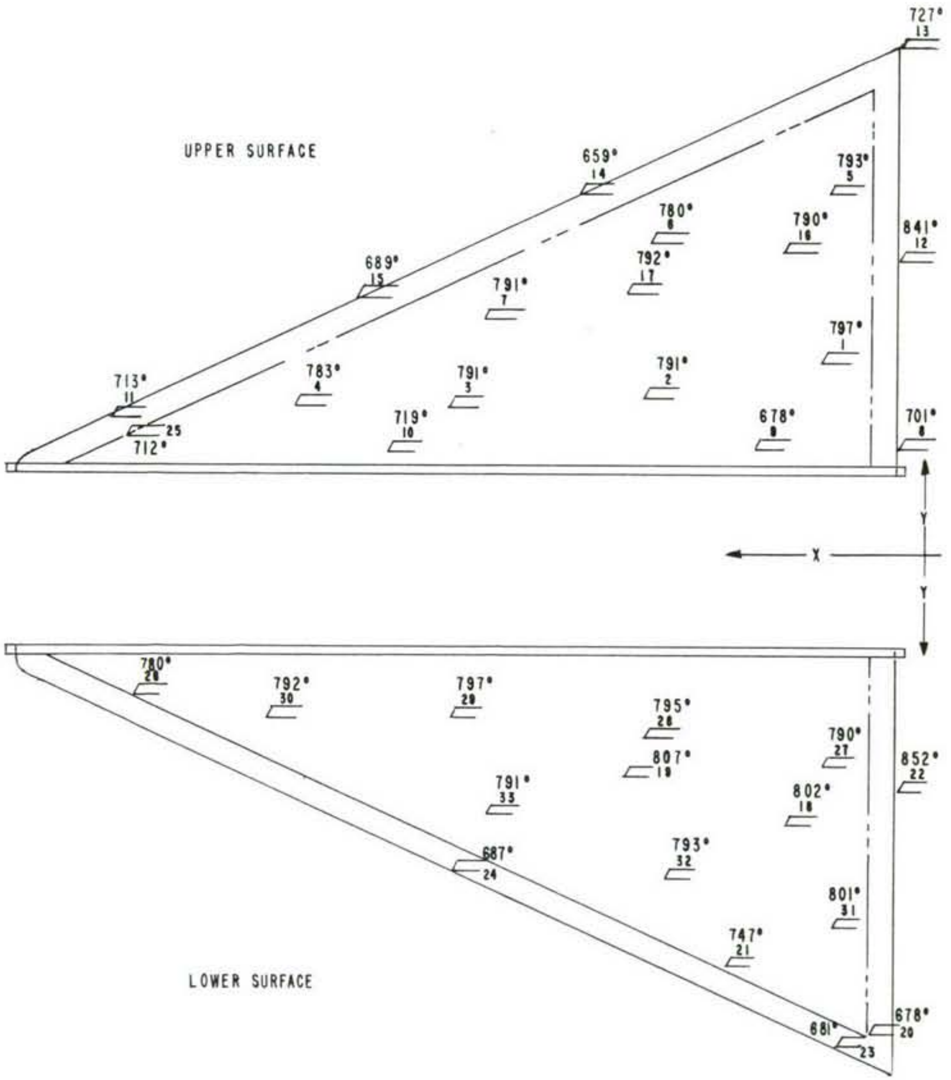

Figure 16. Third Model - Temperature Distribution Prior to Failure

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13. ABSTRACT

Small specimen tests (elevated temperature with internal pressure) were performed to predict the ability of a CS-105 silicone elastomer coated AIRMAT model to withstand the environment of a hypersonic wind tunnel (900-1500°F). The specimens all leaked badly in the expected wind tunnel temperature range. This indicated the probability of subsequent model failure. The wind tunnel model tests were, however, successful. Influence coefficient and vibration tests, both at room and elevated temperature, were performed on AIRMAT models in support of flutter research. As before, the models could not withstand elevated temperature (800°F or above). The laboratory model inflation pressure was 10 psi compared with the wind tunnel model inflation pressure of about 2 psi. Time at temperature and/or an oxidizing atmosphere could be failure factors. Further testing of CS-105 coated AIRMAT structures is needed to evaluate the influence of load, pressure, temperature, and environment on coating characteristics and wire strength.

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influence coefficients						
vibration						

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